UNIVERSITY OF PENNSYLVANIA

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JOHN F. HUMES

A THESIS

IN PSYCHOLOGY

PRESENTED TO THE FACULTY OF THE GRADUATE SCHOOL IN
PARTIAL FULFILLMENT OF THE REQUIREMEMTS FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

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THE EFFECT OF PRACTICE UPON THE UPPER LIMEN FOR TONAL DISCRIMINATION

By John F. Humes, University of Pennsylvania

It has been shown by Cameron that practice is one of the factors involved in the improved discrimination of vocalized tones.[1] Gough has also demonstrated that "practice has a marked effect on an individual's ability to identify musical notes that is distinct from the initial capacity of the individual or from the type of instrument used in producing the notes."[2] These results suggest that practice might increase the sensitivity of hearing to such an extent as to affect the upper tonal limen.

The purpose of this study was, therefore, to discover whether practice affected the upper terminal limen for tone, and, if so, how.[3]

Method and Procedure

A sound-proof room was not desired as silence and freedom from distraction produce in the *Os* a critical attitude toward the stimulus,[4] and as minor distractions have been found to increase accuracy of judgment.[5]

*Accepted for publication April 20, 1929.

[1]E. H. Cameron, Effects of practice in the discrimination and singing of tones, *Psychol. Monog.*, 23, 1917, (no. 100), 179.

[2]Evelyn Gough, The effects of practice on judgments of absolute pitch, *Arch. Psychol.*, 47, 1922, 86.

[3]A series of preliminary observations was made in November and December, 1926, the object of which was to choose suitable *Os* as well as to find a room which would meet the requirements of the experiment. The only room available at that time was an unoccupied office on the third floor of Bennett Hall. In March 1927, a room which was more adapted to the needs of the problem was procured in the Medical Laboratory. Here the investigation progressed until June when it was interrupted by the close of the term. This room was not available in the fall, consequently the experiment was not resumed until December, 1927, at which time a room was obtained, through the courtesy of Dr. R. Tait McKensie, in the Hutchinson Gymnasium of the University. These changes produced no apparent or measurable effect in the results.

[4]D. A. Anderson, Duration of tones, the time interval, the direction of sound, darkness and quiet, and the order of stimuli in pitch discrimination, *Psychol. Monog.*, 16, 1914, (no. 69), 155.

[5]F. O. Smith, The effects of training in pitch discrimination, *Psychol. Monog.*, 16, 1914, (no. 69), 92.

Apparatus. A set of 40 steel cylinders of the Koenig type,[6] ranging from 16,200 to 24,000 d.v. by increments of 200 d.v., were employed.[7] The apparatus used in actuating the cylinders is fully described and pictured by Fernberger,[8] hence its description is omitted here.

The apparatus, it must be said however, eliminated two disturbing sources of error—variations in intensity[9] and in localization.[10] The cylinders were actuated by a falling steel ball.[11] Six balls of uniform weight were used in chance order during the course of an experimental hour. Table I gives the weights, distance of fall, and the resultant energy of the balls at the moment of impact.[12] The accuracy of the measurement of the weights is ±0.0002 grm., and of the distance of fall, ±0.10 cm. The energy of the ball at the moment of impact is the product of the weight of the ball by the distance through which it falls. For the purpose of this experiment we may neglect the slight variation in the third column of Table I and consider the factor of intensity as practically constant.[13]

TABLE I

SHOWING THE WEIGHT OF THE DIFFERENT BALLS, THE DISTANCE OF FALL, AND THE ENERGY OF IMPACT

(Distance of fall 20 cm.)

Ball No.	Weight (grm.)	Energy (grm. x cm.)
1	8.205	164.10
2	8.208	164.16
3	8.213	164.26
4	8.222	164.44
5	8.223	164.46
6	8.224	164.48

Observers. The *O*s, all members of the staff of the Department of Psychology, were Carl Altmaier, Jr. (*A*), F. R. Gillespie (*G*), Francis Irwin (*I*), Dr. Miles Murphy (*M*), Sidney Sanderson (*Sa*), and E. M. Twitmyer (*T*).[14] Their ages ranged between 24 and 35 years. While none of the *O*s was, in the strictest sense, highly trained in psychophysical observation, *Sa* and *M* were more

[6]Manufactured by the Standard Scientific Co., of New York.

[7]Cf. E. G. Boring, The construction and calibration of Koenig cylinders, this JOURNAL, 38, 1927, 125-127.

[8]S. W. Fernberger, An improved apparatus for actuating tonal cylinders of the Koenig type, *ibid.*, 38, 1927, 120-124.

[9]Cf. E. F. Möller, The effect of change of intensity upon the upper limit of hearing, *ibid.*, 33, 1922, 570-577.

[10]Fernberger, *op. cit.*, 120.

[11]*Ibid.*, 123.

[12]Cf. E. W. Scripture and H. W. Smith, Experiments on the highest audible tone, *Yale Studies*, 2, 1894, 105.

[13]C. C. Pratt (Highest audible tones from steel cylinders, this JOURNAL, 31, 1920, 406) found that slight variations in intensity did not significantly alter the relative frequencies of judgments.

[14]I am grateful to the *O*s for their coöperation which extended over a protracted period. I wish also to acknowledge my indebtedness to Professor Fernberger, who suggested the problem and assisted me throughout its course; to Mr. M. R. Wehr, who made the weighings of the steel balls in the Physics Laboratory; and to Mr. John R. Roberts, who supervised the care of the apparatus.

experienced than the others, all of whom had had but slight acquaintance with this type of work. *Sa* and *M*, some years before this experiment was begun, had made several observations on the same material used in the present study; but it was assumed, and subsequent observation bore out the assumption, that the previous experience would exert no influence on this experiment. No indication as to the purpose of the study was made to any of the *O*s. *Sa* and *A* observed during the preliminary series only, for reasons later to be described.

Procedure. In some respects the method follows that used by Möller.[15] *O* was seated with his back toward the apparatus, at a distance of 4 ft. from the center of the cylinder being actuated. The relation of the position of *O* to the arrangement of the apparatus was such that the actuated cylinder was always in the median plane of *O*'s head. The following instructions were read at the beginning of each period of observation: "You will experience a number of auditory sensations. In each case you will immediately report whether the experience was tone or not tone; if tone say, 'Yes;' if not tone say, 'No'."

No further instructions were given. A preparatory signal, 'Ready, now,' preceded the actuation of each cylinder by about 2 sec. Observations were recorded immediately. Since it was desired to study the effects of practice, each response was considered important and consequently recorded. Frequently an *O* would request that a stimulus be repeated, invariably because of doubt as to judgment. Repetition was permitted as often as requested.

The *O*s varied considerably in the length of time required to determine a critical stimulus. When this was once determined, it was made the central stimulus of a series of seven, three of which were the next in order above, and the other three the next in order below that point. The cylinders were then arranged on the apparatus so that the presentation of the stimulus would be in haphazard order. Fifty judgments were made on each cylinder, 350 in all, at every session, for the purpose of calculating a statistical limen. In several instances, however, the number of judgments was greater or less than that just specified, due to difficulty in determining a critical stimulus. Rest periods of from 1-3 min. were permitted after every 100 judgments. Every observational session consumed about an hour.

The psychometric function that determines the upper tonal limen was calculated from the observed relative frequencies of affirmative judgments in accordance with the phi-gamma hypothesis. Urban's Tables[16] were used to simplify the calculations, which are recapitulated in Table II. This table shows the numerical value of the statistical thresholds. The limens (L) and the indices of precision (h) were computed by linear interpolation between successive values.[17]

At the completion of each session the *O*s were asked to write an introspective report, including a statement of the criteria upon which their judgments were based.

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[15]Möller, *op. cit.*, 572.

[16]F. M. Urban, Hilfstabellen für die Konstanzmethode, *Arch. f. d. ges. Psychol.*, 24, 1912, 236-243.

[17]Cf. S. W. Fernberger, A preliminary study of the range of visual apprehension, this JOURNAL, 32, 1921, 123. Also E. G. Boring, Urban's tables and the method of constant stimuli, *ibid.*, 28, 1917, 282.

Results

Statistical limens (L) of tonal quality, measured in terms of frequency of vibration, and coefficients of precision (h) are presented in Table II for every *O*, for every series of experiments.

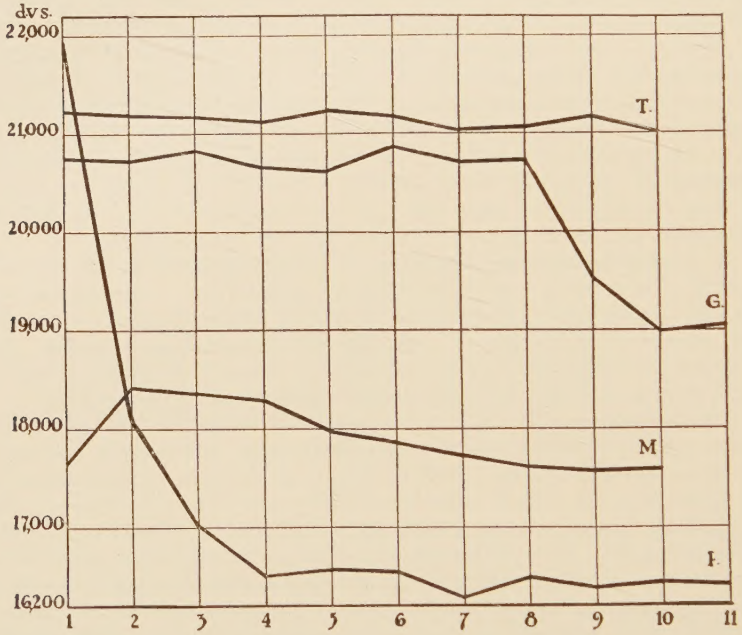

Fig. 1. Showing The Effect Of Practice Upon The Upper Limen Of Tonal Discrimination

Eleven calculations were made for *G* and *I*, and 10 were made for *T* and *M*. It should be borne in mind that these values, because the vibration rates of the tonal cylinders were calculated, have relative rather than absolute validity.[18]

It was expected that practice would increase the magnitude of the upper terminal limen. An inspection of Table II reveals, however, no such result. On the contrary, there is, in the case of every *O*, a noticeable decrease in this value. The higher frequencies, at first experienced as 'tone,' are no longer experienced as such.

[18]Boring, *op. cit.*, 125.

TABLE II

SHOWING THE TONAL LIMEN (L) AND MEASURE OF PRECISION (h) FOR EVERY *O* FOR EVERY SERIES OF EXPERIMENTS

Series	*G*		*I*		*T*		*M*	
	(L)	(h)	(L)	(h)	(L)	(h)	(L)	(h)
I	20750	0.0023	21942	0.0012	21202	0.0019	17641	0.002
II	20741	0.0037	18178	0.0013	21177	0.0022	18402	0.0011
III	20802	0.0026	17056	0.0021	21174	0.003	18359	0.0013
IV	20680	0.0017	16530	0.0013	21124	0.002	18275	0.0018
V	20623	0.0026	16584	0.0016	21251	0.0026	17912	0.0017
VI	20855	0.0022	16569	0.0016	21171	0.0023	17863	0.0024
VII	20706	0.0034	16267	0.0012	21055	0.0021	17754	0.0024
VIII	20745	0.0034	16496	0.0016	21061	0.0023	17668	0.0025
IX	19527	0.0022	16393	0.0018	21167	0.002	17646	0.0016
X	18922	0.0029	16432	0.0011	21019	0.002	17659	0.0024
XI	19056	0.0028	16420	0.0012				

The limens. An examination of Fig. 1, which pictures diagrammatically the results shown in Table II, reveals marked individual differences in the upper limen. There are four well-defined levels, and but one overlapping.

I's limen in Series I is well above that of any of the other *O*s. In Series II, however, his limen drops to a point far below that of *T* or *G* and slightly below that of *M*; and in Series III it drops still further to a point where it is much lower than that of any of the other *O*s. In Series IV, *I*'s limen reaches a point of relative stability. Thus *I* starts out with the highest terminal limen and ends with the lowest. It should be noted here that 9 weeks elapsed between *I*'s first and second series. During that time he observed at 6 different experimental sessions, the results of none of which were sufficiently homogeneous to admit of calculation. Series II was the last one calculated before the close of the regular school year. Between Series II and III there was another interruption of about 9 months. During the latter part of this period (*i.e.* from the first of December, 1927—when work was resumed—to February 23, 1928) *I* observed at 5 sessions the results of which were again so irregular that no limens could be calculated. Series III was obtained during the latter part of February, 1928, Series IV 5 days later; and from then on the different series were obtained at weekly intervals.

Two interruptions occurred in *G*'s work: one between June and December of 1927; and the other between the latter part of December and the middle of the following February when the holidays and mid-term examinations interrupted the work. These interruptions are not reflected in his results. The drop in his limen in Series IX, which was the first value calculated after work was resumed in February, was due, not to the interruption, but to inspissated cerumen of his left ear. This troubled him for over a month. Series X, obtained one week after Series IX, shows a further drop; but Series XI, obtained after an interval of another week, shows a slight rise. Observations obtained still a week later were so irregular that a limen could not be calculated.

Except in the case of *M*, the values as determined at the beginning of the study, are all higher than at the end. The first limen of *M* turns out to be his lowest. The highest value determined for him was in Series II. A steady, though gradual, descent in the curve from this point is apparent up to Series X, which is but slightly higher than the one previously calculated. Successive periods of observation occurred closer together, in point of time, for *M* than for any of the other *O*s, the ten series having been made within two months (April 18 to June 14, 1928). One set of observations, made between Series IV and V, could not be statistically treated.

The curve of *T*, aside from one inversion, which is not strikingly significant, is the most stable of all. While there is a fairly gradual decrease in the liminal values, there is no significant variation except in Series V. For *T*, continuity of observational sessions was interrupted three times. The first limen was determined about the middle of April, 1927; the second, just previous to the December holiday. A lapse of 2 mo. occurred between Series III and IV; and

4 weeks intervened between Series IX and X. These interruptions were due to vacation periods and to *T*'s inability to serve in the experiments. The results plainly indicate that the intermissions were inconsequential. The observations of *T* were uniform throughout, so that in no instance was it necessary to discard any of his results.

Coefficients of precision. Tables of observed relative frequencies are omitted, because of their bulk, but an idea of the comparative steepness of the curves may be gained by considering the coefficients of precision (h). These have been averaged and the mean variation determined for every *O*. The values are as follows: *G*, 0.0027 ±0.0005; *T*, 0.0022 ±0.0002; *M*, 0.0019 ±0.0004; and *I*, 0.0014 ±0.0003. It will be seen from these results that *G* has the highest average h and the greatest m.v.; that *T*'s average h ranks second and his m.v. fourth; that *M*'s average h and m.v. are both in third position; and that *I*'s average h ranks fourth and his m.v. second. On the basis of these results no generalization may be advanced.

The critical stimulus. The value of the critical stimulus varied in the different series for every *O* except *T*.

For *T* the cylinder of 21,200 d.v. was used in all the series. For *I*, however, the cylinder of 22,200 d.v. was used in Series I, of 18,400 d.v. in Series II, of 17,200 d.v. in Series III, and of 16,800 d.v. in Series IV-XI. The cylinder of 21,000 d.v. was used in the first eight series for *G*, but thereafter, because of the condition of the ear referred to above, values of 19,600, 19,000, and 19,200 d.v. were used respectively in Series IX, X, and XI. The values of the critical stimulus used for *M* varied as follows; in the first three series the cylinder of 18,4000 d.v. was used, in the next four series (Series IV-VII) the cylinder of 18,000 d.v. was used, and in the last three series (Series VIII-X) the cylinder of 17,800 d.v. was used.

Numerous attempts were made over a period of 4 mo. to determine a critical stimulus for *A* and *Sa* but without success. These *O*s were tested over the entire range of the apparatus and their reports were so irregular that a limen could not be calculated from them. It is interesting to note, however, that the majority of their reports were positive even in the upper regions of the scale. *Sa*, for example, on an occasion when the cylinders varying from 22,800 to 24,000 d.v. were used, reported "this whole series seemed to be tone, and at no time was I in doubt of my judgment." Of the 70 judgments returned with this series, 63 were 'yes.' There was, however, *Sa* added, "little discriminable difference between the tones."

It was assumed that neither of these *O*s was able to distinguish in this range between tonal and non-tonal qualities and further work with them was therefore abandoned. It was later learned that they both were 'tone deaf,' in the sense that neither could 'carry a tune.'

Discussion of Results

The decrease in the upper terminal limen is due probably to a change in a number of factors, but prominent among them is the criteria employed by the *O*s in their judgments of tone.

The introspections reveal that the subjective standard of judgment changed as the experiment progressed. Thus while no improvement in sensory acuity was noted, the *O*s did develop a higher degree of discrimination in their judgments of a tone. Every *O* became more conservative and critical in his judgments as the experiments progressed.

As Möller has pointed out,[19] a statement of the limen only gives a little of the available information. Adequate interpretation requires an analytic treatment of the results. For the purpose of this study it has been deemed unnecessary to deal with every individual limen, but it is important to examine the introspections since they shed light upon the general aspects of the problem.

(*1*) *Criteria for tone.* Since no attempt was made, in giving the *O*s their instructions, to dictate the criteria of tone, equivocality is perhaps to be expected. We found that the criteria of judgment varied in the early stages of the experiment, not only from series to series, but even during the course of a single period of observation. *M*, for example, reported in Series II:

"The formation and maintenance of a criterion seemed more difficult this session. The experience was very similar to one I have had in grading examination papers, in which I have at times wondered whether my standard has not changed."

There is, however, more or less general agreement among the *O*s as to the characteristic qualities of the stimuli. A sound of a 'ringing' nature is judged as 'tone,' while a 'click' or a 'thud' is described as 'no tone.'

I, for example, said, "I distinguish a tone by its ringing quality. Whenever I hear a twang or a sharpening, I judge it a tone; when I hear just the click of the ball hitting the cylinder, I judge it not a tone." This is of particular interest since it was written after Series I, which is the highest limen calculated in the entire experiment. Thereafter it required stimuli of considerably fewer vibrations to be characterized as 'tone' on the basis of the 'ringing.' This result can be explained, we believe, in no other way than by a shift of attitude.

T, according to his reports and the observed relative frequencies of judgments, maintained a constant attitude throughout the experiment. He writes:

[19] Möller, *op. cit.*, 576.

"I seemed to recognize two series of auditory stimuli. One had the content of a thud—this I called 'no tone.' The second type of stimulus carried with it a sort of 'ring'—this I called 'tone'."

G similarly characterizes 'tone' by "a ring which lasts but a very short time after the blow. If the ball strikes the cylinder with a thud, it is merely a noise. In many cases there is just the slightest suspicion of the ring, yet not enough to be classed as a tone."

M uses the same terms. He says, " 'Tone' is something added to the experience. 'No tone' is a dull thud. 'Tone' is that plus something more. The 'something more' is characterized by duration and a kind of 'ring'."

A and *Sa* use similar criteria in differentiating the experiences. *A* says, "The difference between a tone and not-a-tone is determined largely by the presence or absence of a thud. Whenever I hear the dull thud I judge 'no tone.' The absence of the thud determines 'tone,' but there seems also, in the case of 'tone' to be a 'ring'." *Sa* reports that "a metallic clang with an after-ring seems to be my criterion for tone. 'No tone' is a 'flat' sensation of short duration, lacking the after-ring."

The 'ring' and the 'thud' remain the basic differentia during the entire experiment. But the specific location in the scale where these perceptions occur is by no means constant. This variability is undoubtedly a function of the stimulus attitude.

(*2*) *Intensity.* The objective variations in intensity were, as shown in Table I, negligible, yet the *O*s reported intensive differences in their experiences.

I writes, after Series X, "I particularly noticed a phenomenon which I have noticed before, that the intensity of the sound seem to vary considerably. By intensity I mean the series of experiences which vary from loud to soft which are expressed in music by *forte* and *piano*. The 'tones' seem in general to be louder than the 'no tones,' though I cannot make an accurate statement about this relation."

M (Series VII): "I detected very great differences in intensity, apparently between various stimuli which are judged tone. In some the tonal intensity seems very high, in others faint."

G (Series VII): "Occasionally one of the tone sensations would ring out with more intensity than any of the others before. On the other hand, some of the 'no tones' would come as a gentle rap, entirely unlike any other 'no tones'."

A: "I noticed today that there was a louder tone sensation than I had heard before."

Neither *T* nor *Sa* report intensity differences.

Since the reports were made at the close of an experimental period, it was impossible to identify the particular stimulus that produced a judgment of greater intensity. Occasionally, however, an *O* would voluntarily indicate after the reception of a stimulus, an intensity difference. A repetition of several stimuli (including the one judged more intense) never resulted in the per-

ception of a difference. We feel warranted, therefore, in ascribing the intensive differences reported to subjective factors.

(3) *Auditory after-effects.* After-experiences were reported by some of our *O*s, as shown by the following excerpts from the introspections.

T (Series I): "[One] type of stimulus carried with it a sort of ring, or what seemed to be a momentary continuation of the initial impact. I think of it as an after-effect as distinguished from the abruptness of the first type ('no-tone'). This I called tone, for it seemed to carry more than the initial impact."

M (Series I): "Tone seems longer in duration than 'not tone.' The 'not tone' is a click or a thud which is brief and quickly gone. Tone 're-echoes,' as it were. Whether these echoes which seem to add to the duration of the sensory experience are aspects of the sensation primarily, or after-images, I am not able to say." After Series X, he writes, "the presence of pitch seems to carry with it a gradual, uniform falling away of sound."

Sa: "The tonal sensation always lasted longer; it is a ringing sensation followed by an echo-like effect."

Obviously differentiation of tone and not tone depends, to a large extent, upon the relative duration of the perception. The writer inclines to the belief, however, that the 'after-experiences' reported by the *O*s are not after-images analogous to the after-images of vision, but that they are either Bishop's 'modified endings,'[20] or experiences derived from the prolonged vibration of the stimulating media, or memory after-images. The results are not at hand to enable us to decide which of these is the true explanation.

(4) *Assurance and doubt.* The *O*s were not instructed to report the degree of certainty with which judgments were made. Consequently, subjective assurance is not indicated in definitely quantitative terms. Nevertheless, it seems certain, from the references made by the *O*s to the "difficulty of the task," to the fact that they "were guessing at first," to the "feeling of uncertainty" regarding their judgments, and from the numerous requests for a repetition of the stimuli, that the difficulty experienced by the *O*s in establishing constant criteria was in a large measure due to uncertainty. This is in agreement with Boring's statement that "doubt is the most constant offender" in the control of attitude.[21]

[20]H. G. Bishop, An experimental investigation of the positive after-image in audition, this JOURNAL, 32, 1921, 325.

[21]E. G. Boring, The control of attitude in psychophysical experiments, *Psychol. Rev.*, 27, 1920, 445.

(5) *Expectation and comparison.* The *O*s made a few references in their protocols to expectation[22] and comparison, consequently the extent to which these factors influenced their judgments cannot be definitely established. It is probable, however, that both of these factors were frequently effective. The occasions are chiefly due, we believe, to the chance arrangement of the stimuli in the stimulus-series,[23] therefore, whenever *E* suspected that either was effective, the order of presenting the stimuli was changed.[24]

The tendency to compare a present experience with one immediately preceding it was reported by several *O*s, as the following excerpts illustrate.

G (Series X): "The alternation of 'tone' and 'no-tone' became so evident that I unconsciously pre-perceived what was coming next."

M (Series II): "The sequence seemed important this time. I believe, if a sensation follows one which is positively 'tone,' that it is less likely to be judged 'tone' than if preceded by a doubtful experience. In other words, the judgment is influenced by the preceding experience."

A: "I felt that my judgment was somewhat influenced by the previous one. If a clear tone was heard, then the next one would invariably be a dull thud, which might have been judged a tone had it been isolated in experience."

These reports accord with Fernberger's conclusions in his experiments with lifted-weights,[25] that a stimulus is as likely to be judged one way as another, depending upon its position in the series.

(6) *Affection.* Three of the *O*s, as the following excerpts show, refer definitely to affective accompaniments of the sensory experiences.

I (Series VIII): "I noticed an affective reaction to the auditory sensations. When a sensation is surely 'tone' it is very pleasant; in doubtful cases there is unpleasantness. The greater the difficulty in reaching a judgment, the greater in general the unpleasantness. A sensation which is surely 'not-tone' is also pleasant, though less intensely so than in the case of one that is surely tone."

Sa (in his first report): "Tone is marked by an unpleasant tingling in my ears."

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[22] *Ibid.*, 445.

[23] Cf. S. W. Fernberger, Interdependence of judgments within the series for the method of constant stimuli, *J. Exper. Psychol.*, 3, 1920, 132.

[24] The effect of expectation in pitch discrimination was noted by F. O. Smith (*op. cit.*, 99) who says, "with a strong expectation of hearing the second tone high or low, the organism is set to make the appropriate response and this has a marked influence upon his judgment."

[25] Fernberger, *op. cit.*, 149.

M (Series I): " 'Not-tone' is always more pleasant than 'tone.' The tones are all high and unpleasant, and at times they are almost painful."

The affective aspects of the experience depend, in the case of *I*, not upon the tonal quality, but upon the degree of assurance that attached to his judgments. In the cases of the other two *O*s, tone is either accompanied by unpleasant consequences, *i.e.* a tingling in the ears, or is itself unpleasant. These results corroborate those of Smith—high tones for some of our *O*s are intrinsically unpleasant.[26]

(*7*) *Attentional factors.* Four of the *O*s referred specifically to attention as a factor of importance in their judgments. Maximal attention was required in the experiments. Whenever attention began to wane or to waver the *O*s reported that their judgments became difficult and uncertain. They further reported that they resorted, in such instances, to various tricks, such as opening or closing their eyes, to sustain their attention. Whenever distractions occurred or *O*'s attention was poor the experiments were repeated or temporarily interrupted.[27]

(*8*) *Physiological conditions.* The *O*s reported varying states of health during the course of the experiments. With the exception of *G* none of them, however, suffered anything more than a 'cold in the head.' *G*, as has already been mentioned, suffered from an aural disorder of the left ear.

The disorder of *G*'s left ear was first noticed in Series IX when the critical stimulus (which had been constant at 21,000 d.v.) had to be changed to 19,600 d.v. Our original intention was, when we discovered this defect, to exclude the results and to hold up further observations until *G* had recovered. It was decided, however, to report them and to continue the experiments, because the results were considered to be of theoretical significance.

There are two possible explanations for the decrease in *G*'s sensitivity in Series IX, X, and XI. The impacted ear-wax may have lowered the intensity of the stimulus and this may have resulted in the lowering of the limen. This explanation stands, however, in opposition to the results of Möller's study in which she investigated the effect of changes of intensity upon the upper limit of hearing. She found that the upper tonal limen did not vary with intensive

[26]Smith, *op. cit.*, 87.

[27]It was necessary in a few isolated instances to suspend work because of adventitious sounds. The observations made during such periods were discarded.

differences.[28] The impacted ear-wax may, on the other hand, have resulted in the functional loss of *G*'s left ear and this may have resulted in the lowering of the limen. This explanation stands in line with the results of Knudsen[29] and Young.[30] Both of these investigators found that sensibility is greater when both ears function together than when either functions separately. That *G* was, during the last three series of experiments, observing monaurally, is borne out by one of his introspections. He said, after the experiments of Series X, "The condition of the left ear was worse than ever before. None of the stimuli were heard in that ear. After realizing this, attention was directed to the right ear."

It is not clear, however, why the monaural limen should be lower than the binaural. Even though it be granted that the intensity of the stimulus is less in monaural than in binaural hearing, intensity may not, in the light of Möller's results, be used to explain the difference.

I's health may have been an important factor in the early stages of the experiment. After several experimental periods when his results were particularly irregular, he reported feeling "not physically well." After Series III, when he was approaching a standard criterion which he later used throughout the experiment, he wrote, "Today I am feeling better than at most, perhaps all, of the other sessions."

M reported a 'cold' on a day when his observations were too erratic to be computed. *T* likewise reported a 'cold,' during Series VI, which he believed had affected his left ear; his results did not, however, bear that out as they were not noticeably affected.

While we cannot generalize, it appears from these results that the *O*s, in order to return the best possible reports, should be in a good state of physical health.

(*9*) *Other factors:* (*a*) *Kinaesthesis.* *I* was the only one of the regular *O*s to mention kinaesthesis. He described his experience of tone as being "more like a sharp thudding against the ear than an auditory sensation." Both *A* and *Sa* referred in the preliminary experiments to kinaesthetic experiences. *A* reported that "the tone was determined by a feeling of vibration . . . a greater fullness in my ears than in the case of 'no-tone'." *Sa* observed "an unpleasant tingling in my ears." And again that "at times there was a distinct kinaesthetic sensation inside the ear."

Just how much the awareness of muscular strain entered into the *O*'s judgment can not be decided here. The results offer no clue as to the effect of

[28]Möller, *op. cit.*, 577.

[29]V. O. Knudsen, The sensibility of the ear to small differences of intensity and frequency, *Phys. Rev.*, 19, 1923, 84-102.

[30]R. C. Young, Binaural *vs.* monaural sensibility of the human ear to small differences in frequency, this JOURNAL, 37, 1926, 328.

kinaesthesis, nor do the introspective reports provide us with adequate material for a conclusive statement. We are, however, of the opinion that kinaesthesis is of definite importance and that it should not be disregarded.

(*b*) *Imagery.* On the basis of the introspective reports, imagery is relatively unimportant in these experiments, yet it must have been involved in them. It must have served, for example, as the basis of the factors of expectation and comparison discussed above. While not clearly described as such by any of the *O*s, the comparison of a present auditory experience with a preceding one evidently took place in imaginal terms, *i.e.* the memory of a preceding tone persisted long enough to be compared with a present one. Furthermore, the auditory 'after-effects' described above, may have been, as we remarked, nothing more or less than memory after-images.

(*c*) *Localization.* Localization, as the term is used here, means the general region of *O's* body at which the sound 'registers.' *G*, for example, stated (Series I) that "consciousness of the sound seemed to be in back of the head." After the last series he made a rough diagram of his head, indicating the various regions where the different qualities of the auditory experience were localized. *A* localized the tones, similar to *G*, in his head, although the localization was probably made in kinaesthetic rather than visual terms since he referred to a "decidedly sharp vibration in my head."

(*d*) *Volume.* Volume was seldom referred to in the introspective reports.[31] *I* stated in two reports, however, that some tones seemed "fuller" than others. *G*, on one occasion, mentioned that one of the tones had greater volume than the others. *Sa* also noted a variation in volume. It is difficult to say, however, whether these references are to imaginal contents or to actual perceptions of differences in volume.

(*e*) *Synaesthesis. M* alone manifested synaesthetic phenomena. After Series I he made the following statement, "There are many visual synaesthetic experiences. Tone is a dark circle with rays of light streaming from it; not-tone does not possess these radiations."

Summary

A review of the foregoing introspections indicates that even in a situation where the *Aufgabe* is relatively simple, a great deal of complexity may exist. It is well to repeat that a mere statement of the qualitative limen is insufficient for a complete comprehension of the problem. A consideration of all the relevant material available is necessary for the adequate interpretation of responses to the stimuli here employed.

Individual differences are in general greater than the variations of the judgments of the individual *O*s. We find the various *O*s placing emphasis upon different attributes of the mental process that led to their judgments.

[31] Massiveness or extensity of tone is the meaning here implied.

G, for example, made nine references to 'attention,' the focalization of which was consciously made and extremely necessary for a clear-cut judgment. Localization and imagery seemed to be fused in the three references which he made to these factors. His physical condition was also of concern to him, particularly in the later series, when his left ear was impacted. He referred to this condition three times, and every time in connection with the difficulty experienced in discrimination of tonal quality. He made but one reference to kinaesthesis, volume, intensity, after-image, and comparison and expectation.

I, on the other hand, placed greatest importance upon the degree of subjective assurance which accompanied his judgments. He made nine specific references to this factor. In the early stages of the experiment his unstable physical condition was mentioned four times in the reports. It is believed that this fluctuation of *I*'s general health was largely responsible for the long period required to establish a critical stimulus.

It is of interest to note the change that took place during the experiment in his criteria of judgment since it is more marked in his case than in the other *O*s. After Series II (computed two months after Series I) he said, "Today I seemed to have changed my criterion of tone somewhat. There seemed to be three fairly distinct types of sounds; those clearly not tones, those clearly tones, and a sort of middle class which did not have the sharp twang of what I have been calling tones, but had a kind of bell-like ring. These I called tones." Nine months later, after Series III had been completed, he stated, "In judging today I made a conscious effort to stabilize my criterion of tone by deciding to answer 'Yes' to all cases where I thought the odds were even or better; to all others, I answered 'No.' I used this criterion consciously only in doubtful cases." The next series was calculated one week later, and the same criterion was reported. *I* maintained this standard of judgment for the rest of the experiment; and it will be noted that there is but slight variation in the psychometric function from this point on.

I referred twice to attention and once to affection as factors which aided in subjective assurance. Scattered through his reports are single allusions to volume, kinaesthesis, and intensity.

T's emphasis was upon the temporal differences between 'tone' and 'no-tone.' There was no departure from this criterion. One reference to a 'cold in the head' was all that broke the uniformity of his reports. The maintenance of so constant an attitude resulted in the most stable psychometric function of all the *O*s.

M referred to a number of factors contributing to his judgments, but no one of them was emphasized. After Series I he reported, " 'Tone' is differentiated from 'not-tone' by other modalities as much as by audition." From this it would seem that for him the total mental state was important at the time of a judgment. *M*'s criteria of tone varied more than *T*'s or *G*'s, and less than *I*'s. By deciding to assign 'doubtful cases' to the category of 'no-tone,' *M* made his criteria more rigid. He did this at Series IV. From then on there is a more constant decrease in the liminal value for him than for any of the other *O*s. *M* mentioned, in his introspective reports, attention, auditory after-effects, and synaesthesis each twice, and affection, imagery, comparison, physical condition, and intensity each once.

Conclusions

The following conclusions may be drawn from the results of this study.

(1) The effect of practice is to decrease the upper tonal limen.

(2) Within the limits of the psychometric function, the individual *O* becomes more discriminating of qualitative differences.

(3) Marked individual differences are apparent in the qualitative psychometric functions for these four *O*s. Differences are also evident in the rate and degree of decrease of liminal values.

(4) There is a tendency, once a criterion is rigidly established, for the threshold to remain approximately constant.

(5) Introspective data, which supplement the psychometric are necessary for a complete interpretation of the statistical limen.

(6) Practice does not consistently affect the coefficient of precision, although the trend is in general toward stabilization of that value.

(7) A radical change in the qualitative threshold is largely a function of change of attitude.

(8) For one *O*, an incipient pathology of the auditory mechanism results in a decided obtuseness of qualitative sensitivity.

(9) Qualitative judgment depends upon an integration of auditory attributes and complex mental processes, as well as upon structural constituents, *i.e.* perceptual and imaginal contents.